TECHNICAL APPENDIX C

HYDRAULICS

In Support of Section 1135
Aquatic Habitat Restoration at
Santa Ana Pueblo, New Mexico

Prepared for

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C. HYDRAULICS

C.1 Introduction

Hydraulic modeling was performed to support the habitat restoration plan for the Rio Grande within the Pueblo of Santa Ana. The habitat restoration alternatives described in this document are intended to increase both aquatic and riparian habitat areas in the reach over existing conditions. These alternatives are designed to work in conjunction with the Gradient Restoration Facilities (GRFs) that were designed and constructed under a separate Section 1135 project (USACE 2002). The GRFs provide long-term grade control through the reach that makes other habitat restoration alternatives feasible.

Extensive hydraulic modeling was conducted to support the design and analysis of the GRFs. Those same models were used as the basis for modeling the habitat restoration alternatives described in this section. Complete documentation of the hydraulic modeling and design of the GRFs can be found in the technical appendices for that project. Some review of that information is included below for background.

Hydraulic models were developed previously for the GRF project for existing conditions, the future no-action condition, and the project condition with two GRFs. For this project, the GRF model was revised to analyze both overbank lowering and channel widening alternatives. Both 1- and 2-dimensional models were used as described, along with the results, in the following sections.

C.2 1-Dimensional Hydraulic Modeling

C.2.1 Methodology 1-Dimensional Hydraulic Modeling

Initial 1-dimensional modeling was conducted for a comparative analysis of historical trends of channel geometry and hydraulic characteristics for the Santa Ana Reach of the Rio Grande. This model consisted of six cross sections through the project reach at the Cochiti Rangelines. Detailed 1-dimensional hydraulic modeling was then conducted and included approximately 60 cross sections throughout the Santa Ana Reach. This detailed model was used to evaluate existing conditions, sediment transport, stable channel design and preliminary design of restoration alternatives.

Hydraulic backwater models such as HEC-RAS, HEC-2 and WSPRO are 1-dimensional in the sense that water surface profiles are computed in a linear dimension along the assumed flow path. The HEC-RAS model used for this analysis solves the energy equation (and momentum selected optionally for bridge constrictions) and continuity for reaches and networks of waterways. The input data includes a geometric description of the waterway and steady-state boundary conditions (discharge and stage). The geometric input includes cross sections describing the main channel and floodplain of the waterway and reach lengths between the sections. Each cross section is a profile along a line that is normal to the expected flow direction. Hydraulic resistance is specified for the cross sections in the form of Manning's n values or equivalent roughness height. Reach lengths are entered for the main channel and overbanks of each cross section. The reach length is the distance downstream along the flow path to the next cross section. Boundary conditions in HEC-RAS are usually entered as steady flow rates at the upstream end of the model (additional flows or flow losses can be entered within a model reach) and a stage or stage-discharge relationship at the downstream end of the model. Typically a normal depth option is used when the downstream water surface elevation is unknown. This option requires an energy slope to be entered for the computation.

C.2.2 Initial 1-Dimensional Hydraulic Modeling

The initial hydraulic modeling utilized cross sections from Cochiti Rangelines in the Santa Ana Reach (CO-24 through CO-30) as shown in **Figure C.1**. These rangelines have been surveyed regularly prior to and following construction of Cochiti Dam. Therefore they provide a record of changes in channel geometry through time. Cross section spacing ranges from approximately 0.5 mile to 1.8 miles over the 6.5 mile model length. Hydraulic results from the 6 cross sections at rangelines CO-24 through CO-29 were used for the comparative analysis. Rangeline CO-30 which is approximately 1.5 miles downstream of the Highway 550 Bridge in Bernalillo was used as a boundary condition for the model and therefore not included in the comparative analysis results.
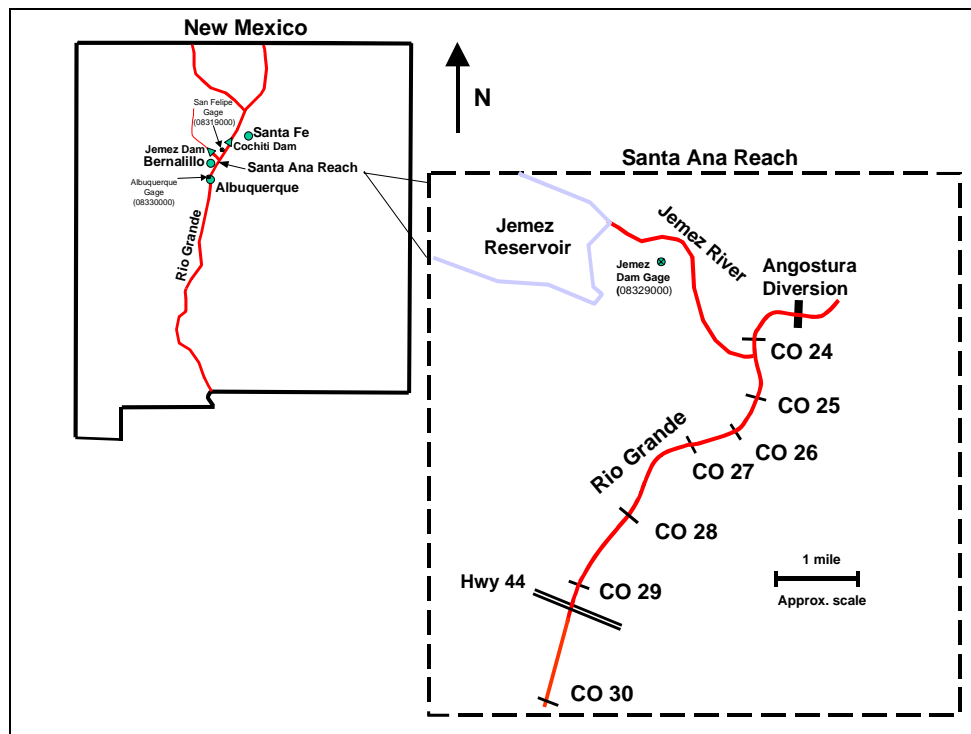
Figure C.1. Location of Cochiti Rangelines for initial 1-dimensional hydraulic modeling.

The initial modeling incorporated cross section data from the Middle Rio Grande Database (Julien et al. 1999). Hydraulic models were developed to represent the Santa Ana Reach of the Rio Grande for 1971, 1975, 1986, 1992, 1995, and 1999. The database included surveyed station elevation data between vegetated banklines. These data were used to develop the hydraulic model geometry. Bosque overbank topography was included for the 1971 and 1975 models because this portion of the floodplain was still active at the modeled discharge. The post-dam effective discharge of 5,800 cfs was used as the discharge for the historical model simulations. For the downstream boundary condition, the normal depth option with a slope of 0.0009 was used for all of the historical models. This slope was a convenient value to use because it is between the reach average slopes of 1971 and 1999.

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The hydraulic model geometries included Manning's roughness values of 0.03 and 0.07 for the main channel and overbanks, respectively. These values were used as initial estimates and were later calibrated based on field data (discussed in the following section). Reach lengths between individual cross sections were measured along the main channel flow path using rectified aerial orthophotographs. The models were run and reach averaged hydraulics were computed for the comparative analysis. Reach averaging of hydraulic variables was computed by weighting the values calculated at individual cross sections based on length. Slopes were determined using linear regression of the computed energy grade and water surface elevations at individual cross sections.

Results from the initial 1-dimensional hydraulic modeling are presented in **Table C.1**. The slope value is the average of the water surface and energy grade slope determined from regression.

Table C.1. Reach Average Main Channel Results From Initial 1-Dimensional Hydraulic Modeling of Cochiti Rangelines (Q = 5,800 cfs).				
Model Year	Hydraulic Depth (ft)	Velocity (fps)	Topwidth (ft)	Slope
1971	2.7	3.0	580	0.001024
1975	2.9	3.2	525	0.001016
1986	3.6	3.5	477	0.000929
1992	4.7	4.0	288	0.000855
1995	4.8	4.1	292	0.000844
1999 and Future without-project	5.1	4.3	259	0.000878

C.2.3 Detailed 1-Dimensional Hydraulic Modeling

Detailed 1-dimensional hydraulic modeling of the Santa Ana Reach was performed for preliminary design of restoration alternatives. The detailed modeling utilized survey data from approximately 60 cross sections with spacing ranging from approximately 300 ft to 1,000 ft. Locations of the Cochiti Rangelines (CO) are shown in **Figure C.2**. All of the model cross sections were surveyed in August 1999 to provide a representation of the existing conditions in the reach. As with the historical cross sections, the 1999 survey only included the channel between vegetated banklines. Bosque overbank topography was added to the models for the purpose of modeling higher flow events. Overbank topography was developed from a digital terrain model (DTM) developed in1992 for the USBR, Albuquerque Area Office.

A calibration of the detailed 1-dimensional hydraulic model was performed using measured water surface elevations and estimated discharges. Water surface elevations were measured during the cross section surveys and mean daily discharges were recorded at the USGS gaging stations at Albuquerque (station # 08330000) and San Felipe (station # 08319000) shown in Figure C.1. An average of the values recorded at these two gages could be representative of the discharge in the Santa Ana reach. To better estimate the discharge in the Santa Ana reach based on the gage records, discharge measurements observed within the Santa Ana Reach from prior surveys were utilized.

Direct stream discharge measurements were collected upstream of the Highway 550 bridge from 1992 to 1996. These measurements were collected for development of the sediment discharge rating curve in the Santa Ana Reach (FLO 1998). The data included a total of 33 measurements covering discharges from approximately 600 to 6,000 cfs. A regression analysis of the measured discharges and the discharges reported at the San Felipe and Albuquerque gages was performed. The regression yielded the following equation to estimate the discharge in the Santa Ana reach given values from the two USGS gages (**Figure C.3**):

$$Q_{SA} = 0.9324 \ Q_{avg} + 17.841 \qquad\qquad (C.1)$$

where:

Q_{SA} = Estimated discharge in the Santa Ana Reach (cfs)
Q_{avg} = Arithmetic average of discharges reported at the San Felipe and Albuquerque gages (cfs)
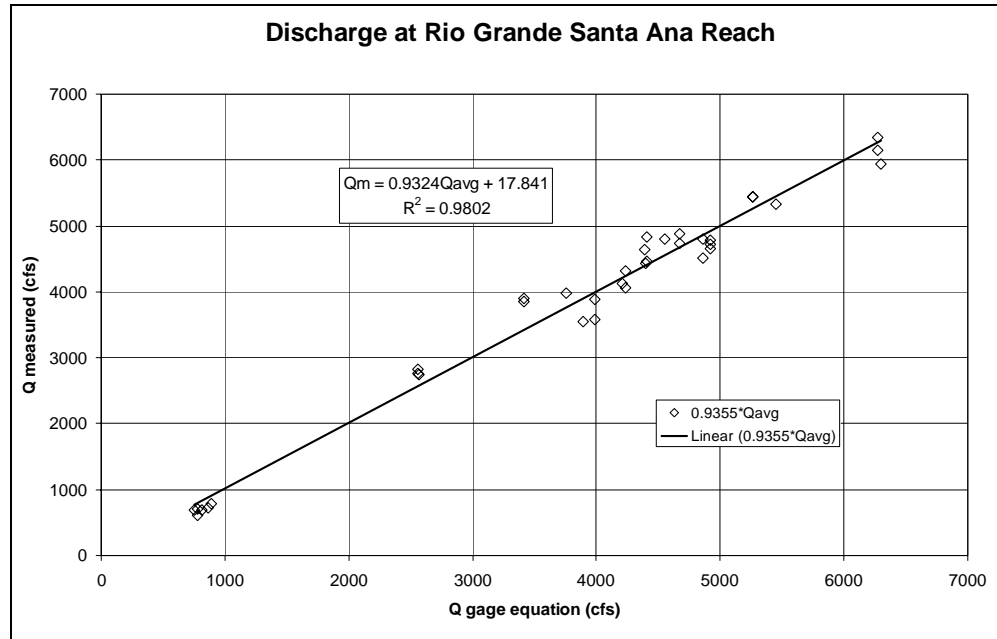
Figure C.2. Regression analysis of discharge in the Santa Ana Reach.

During the August 1999 cross section surveys the discharge ranged between approximately 1,000 and 3,000 cfs. These discharges were used to calibrate the detailed 1-dimensional model. The calibration process involved adjusting the main channel Manning's n value to minimize the error between the computed and measured water surface elevation. Since the reach is fairly uniform, transition losses were considered to be negligible and consequently have little effect on the calibration. Because the cross sections were surveyed over a period of approximately 10 days, various discharges were used in the calibration. Groups of cross sections surveyed on the same day were calibrated at the same discharge.
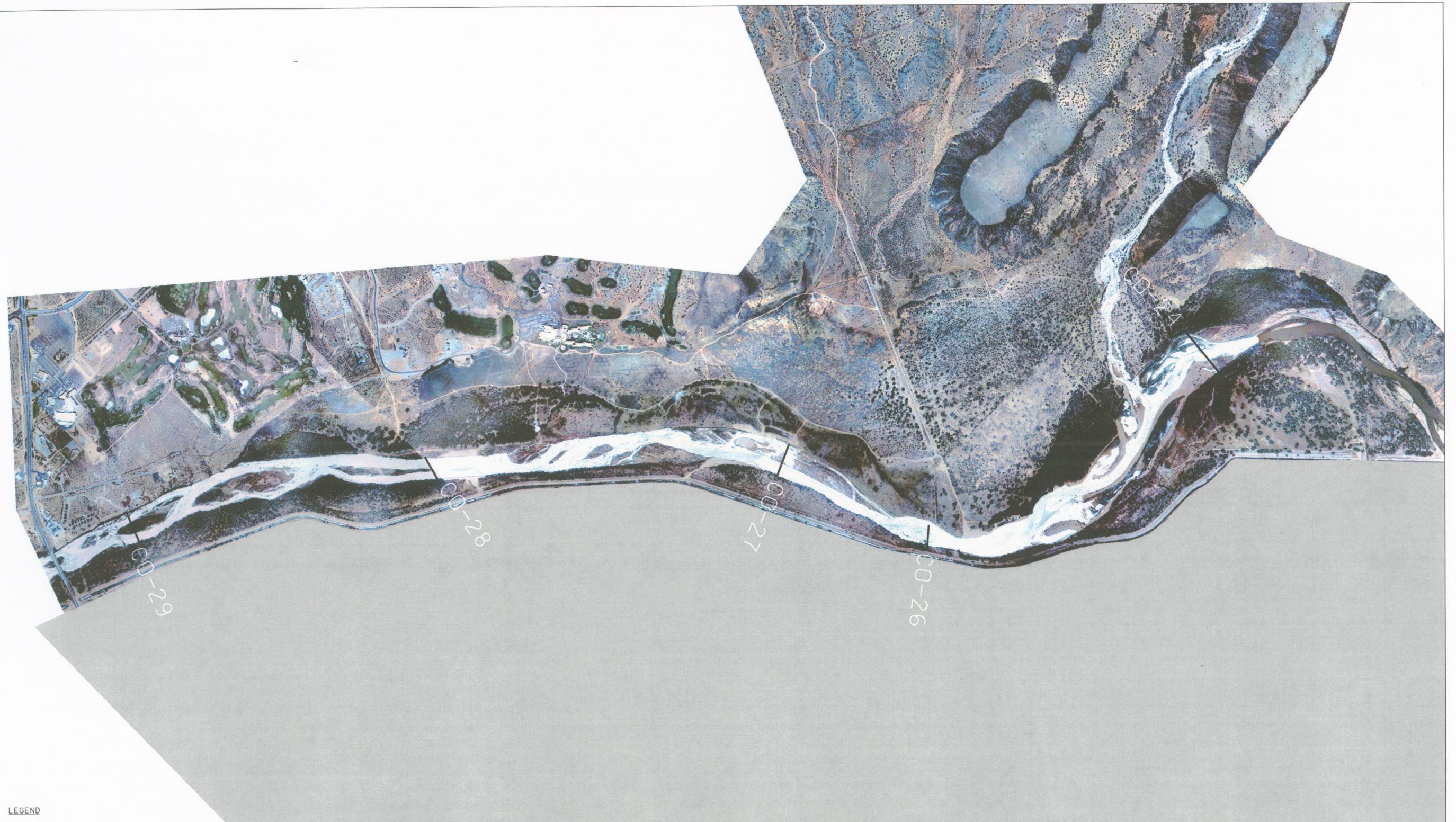
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LEGEND

CO-28 Cochiti Rangeline
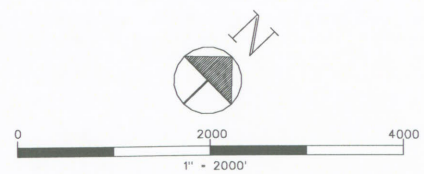
FIGURE C.2
PUEBLO OF SANTA ANA

1-DIMENSIONAL HYDRAULIC
MODELING PLAN VIEW

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0   2000   4000

1" = 2000'

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The computed and measured water surface elevations are presented in **Figure C.4.** Observed water surface elevations are represented with symbols whereas elevations computed with the HEC-RAS model are represented with lines. Generally the computed elevations were within 0.5 foot of the measured elevations. The calibration resulted in main channel Manning n values ranging from 0.024 to 0.032. Overbank n values ranged from 0.031 for unvegetated sandbars to 0.09 in the bosque overbank.

C.2.4 Model Simulations - Existing Conditions

The calibrated hydraulic model was used to determine existing conditions in the project reach. As an initial step, inundation levels for varying discharges were computed. This was performed to determine the potential for overbank flooding under existing and future conditions on the river. Floodplain delineations for discharges ranging from 1,000 to 22,300 cfs (100-year) were developed as shown in **Figures C.5 to C.11**. The floodplain delineations indicate that the bosque floodplain does not currently experience inundation for discharges less than 10,000 cfs. The bosque floodplain is identified as the portion of the overbank that has historically been vegetated with cottonwood and more recently been invaded by salt cedar and russian olives. The hydraulic models indicate that the bosque begins to experience some flooding near the 50-year return period discharge of 15,300 cfs as reported by U.S. Army Corps of Engineers (Beach 1997). The delineations also indicate that much of the sandbars within vegetation lines are not inundated at the effective discharge of 5,800 cfs, and up to 7,500 cfs which is in excess in the USACE 10-year flood of 7,100 cfs.

Comparison profiles of water surface and overbank elevations provided information on the feasibility of restoring bosque flooding at higher frequency flow rates. Since many natural rivers experience overbank flooding at approximately the 2-year discharge, the feasibility of restoring this flooding potential was investigated. Hydraulic modeling revealed that the west bosque floodplain was approximately 4 feet above the existing water surface profile at the effective discharge of 5,800 cfs as shown in **Figure C.12**.

Therefore a 4-foot rise in water surface elevation at 5,800 cfs would be required to initiate bosque flooding at this discharge. Achieving this increase in water surface appears infeasible considering the project constraints and goals.

C.2.5 Hydraulic Design

The hydraulic design for the restoration project was to enhance aquatic and riparian habitat conditions in the lower Santa Ana Reach. The lower Santa Ana Reach is designated as the river downstream of CO-26 to the downstream limit of the Santa Ana property approximately 2,500 feet upstream of CO-29 (reference Figure C.2).
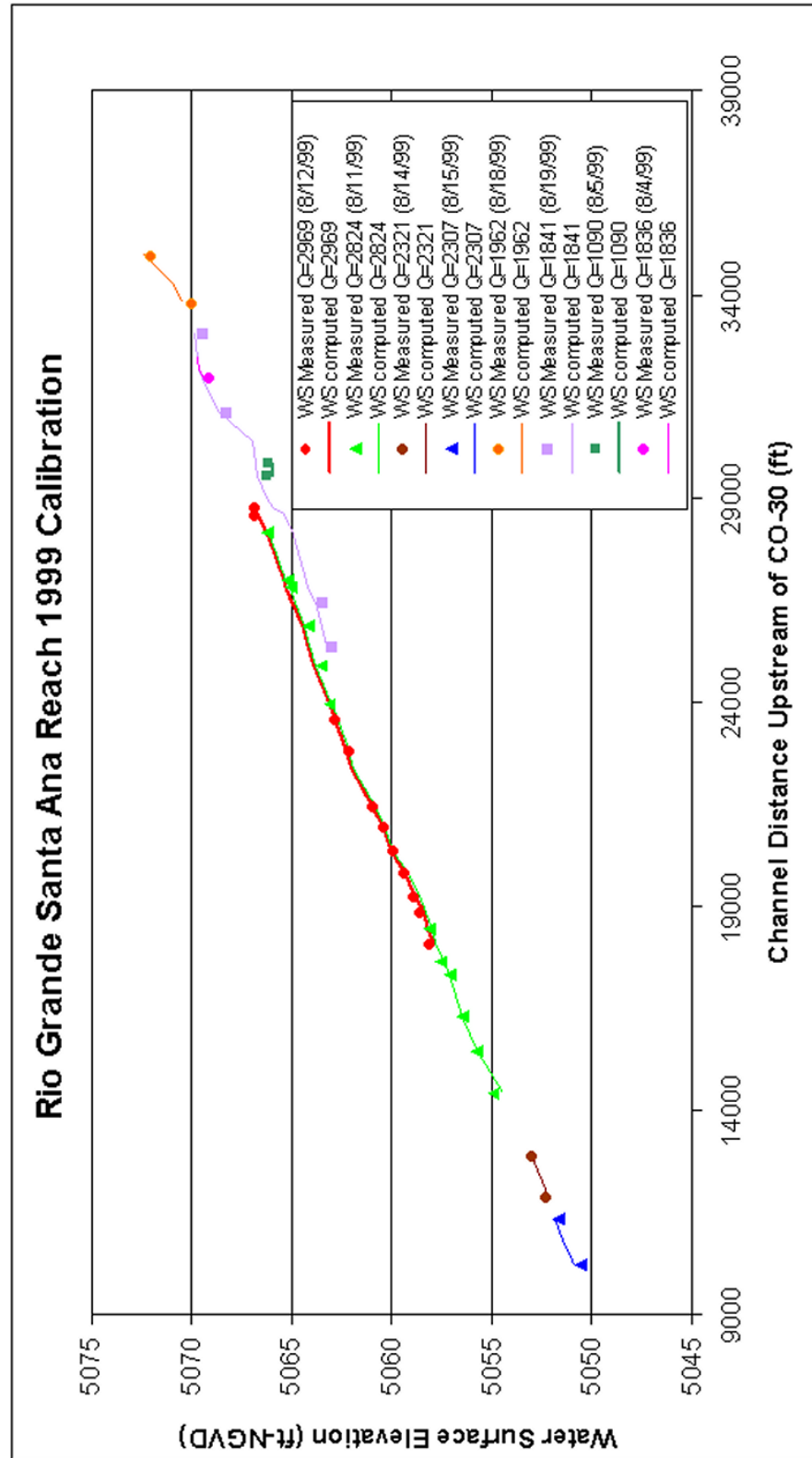
Figure C.4. Measured vs. computed water surface elevation.

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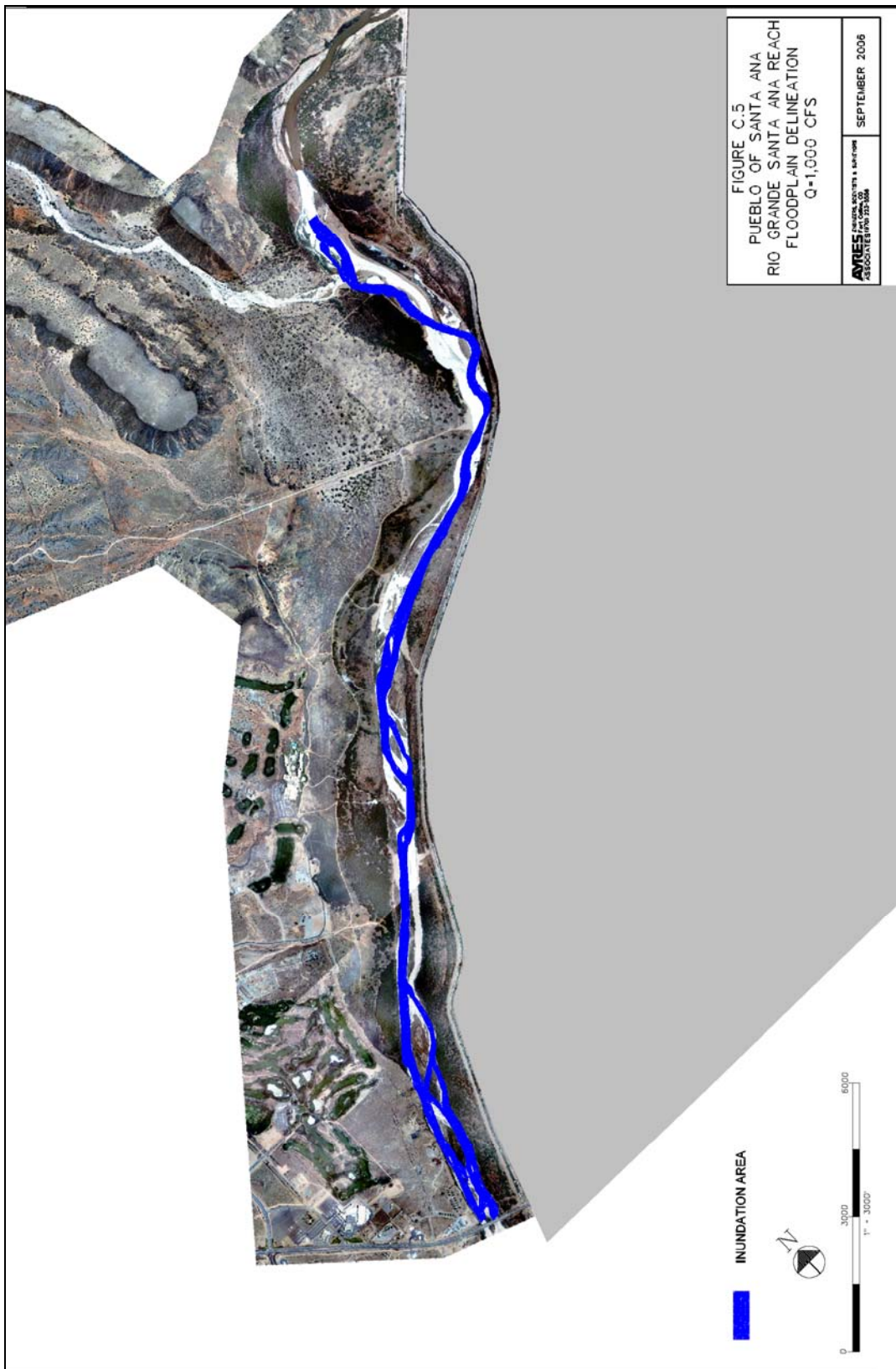
Figure C.5. Floodplain delineation for 1,000 cfs.

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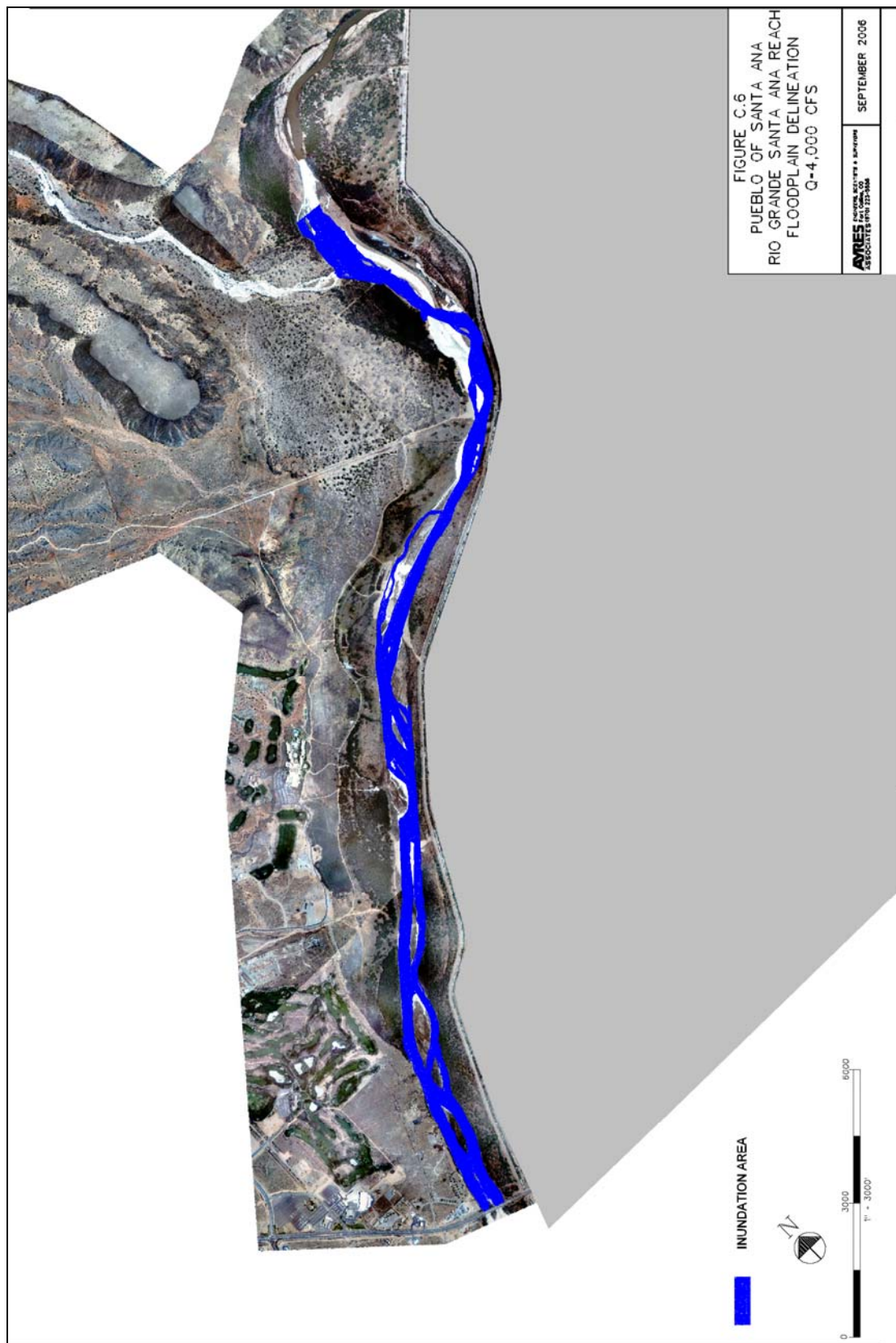
Figure C.6. Floodplain delineation for 4,000 cfs.

C.10   Ayres Associates
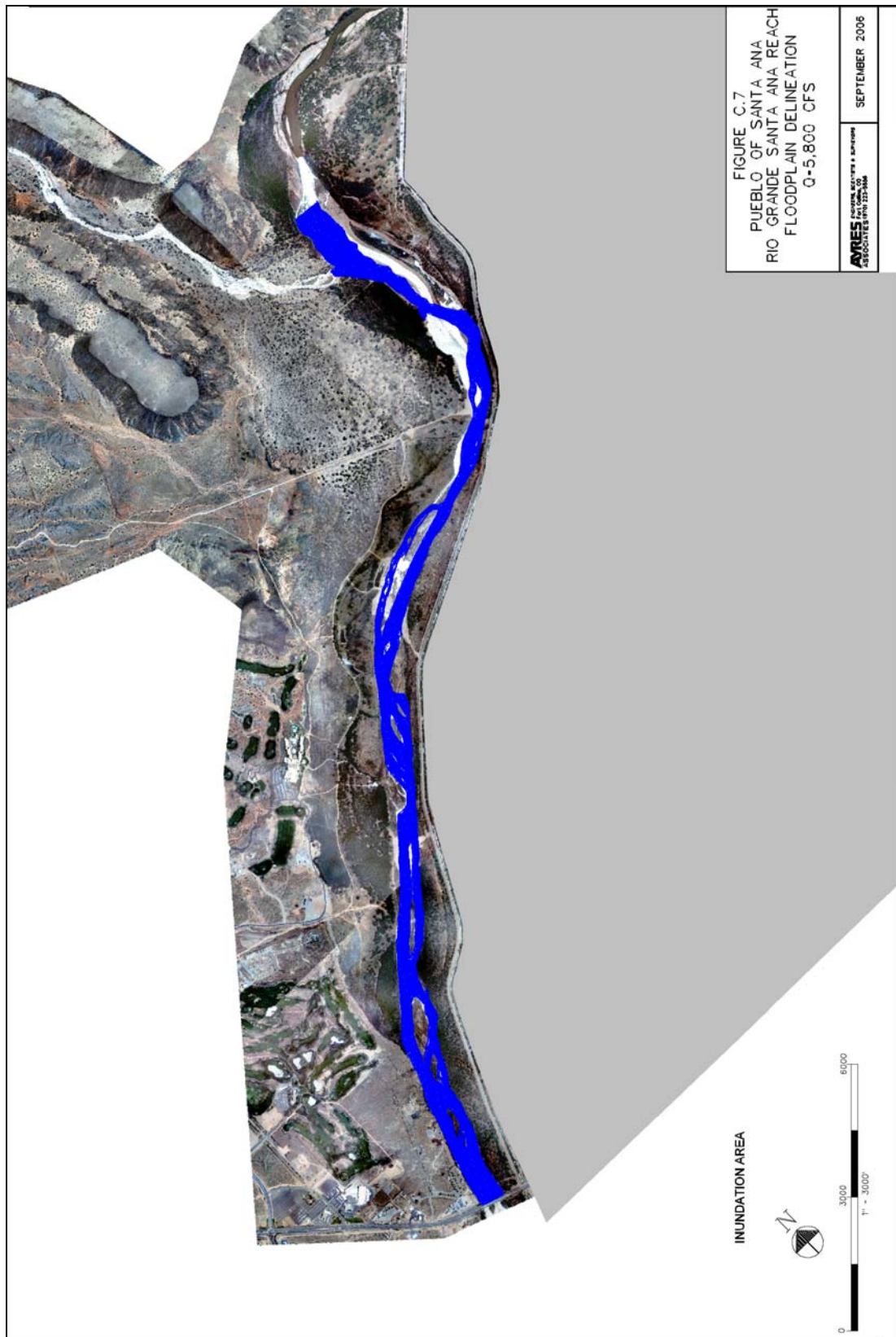
Figure C.7. Floodplain delineation for 5,800 cfs (effective discharge $\cong$ 2-year).

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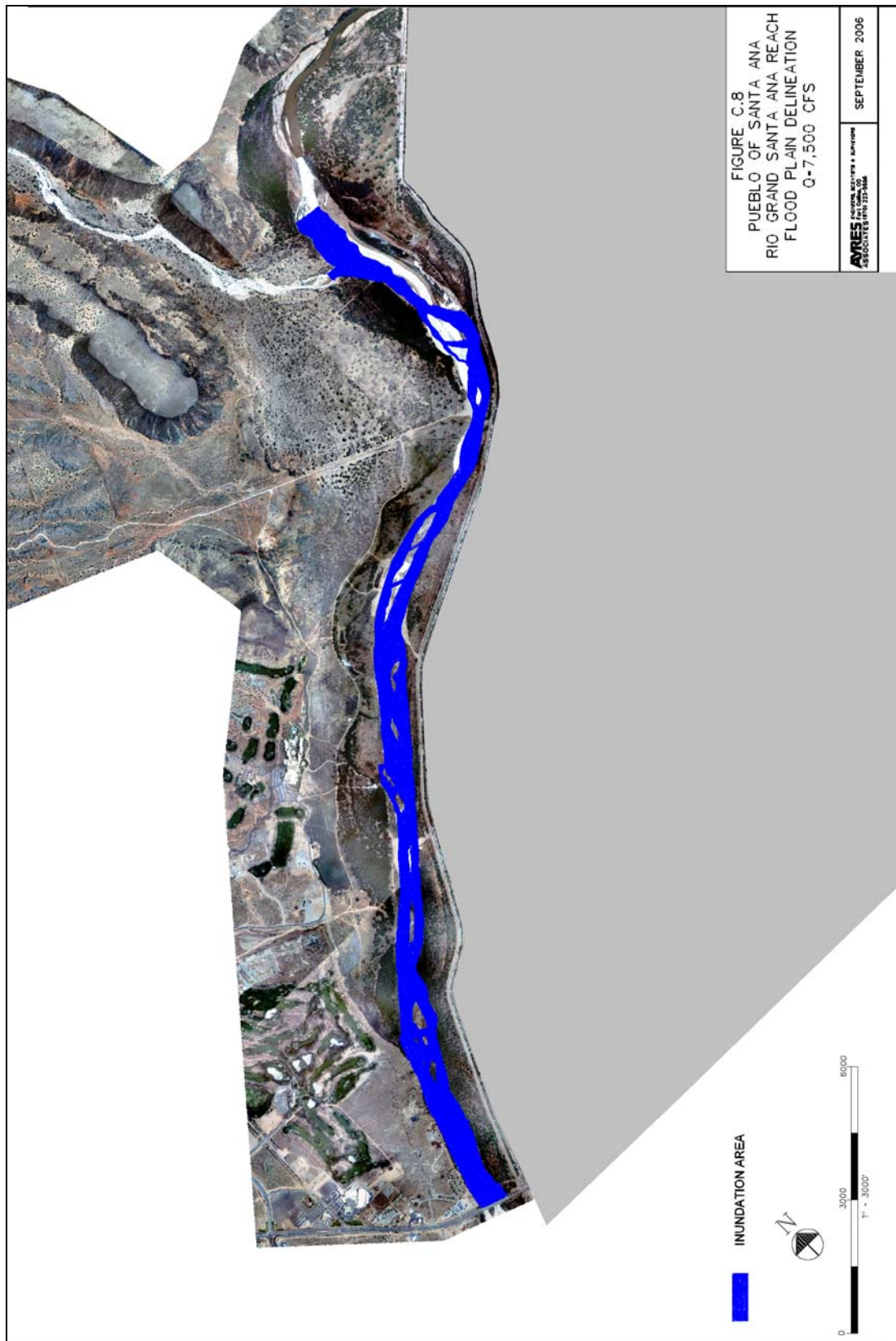
Figure C.8. Floodplain delineation for 7,500 cfs (> 10-year).

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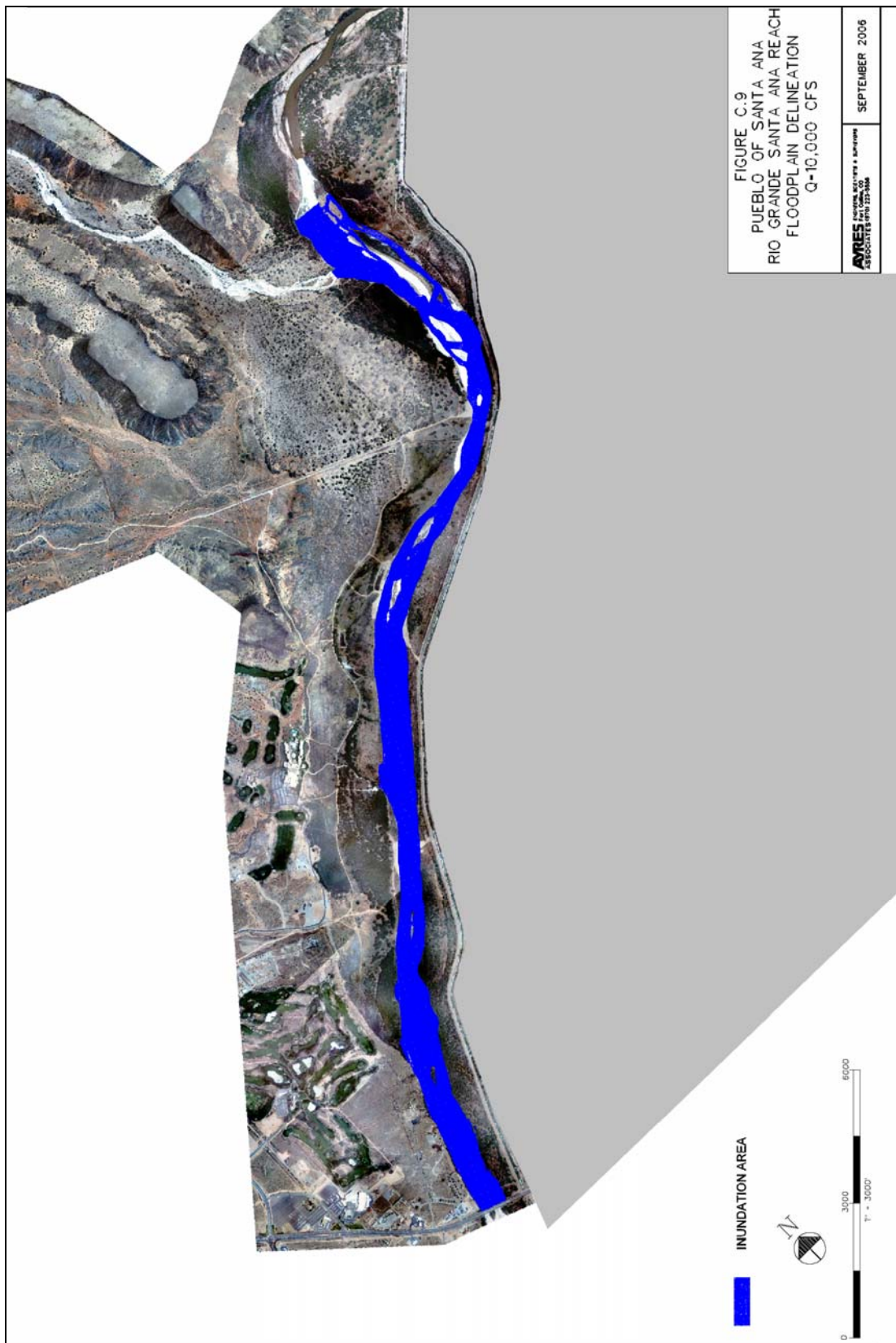
Figure C.9. Floodplain delineation for 10,000 cfs ($\cong$ 25-year).

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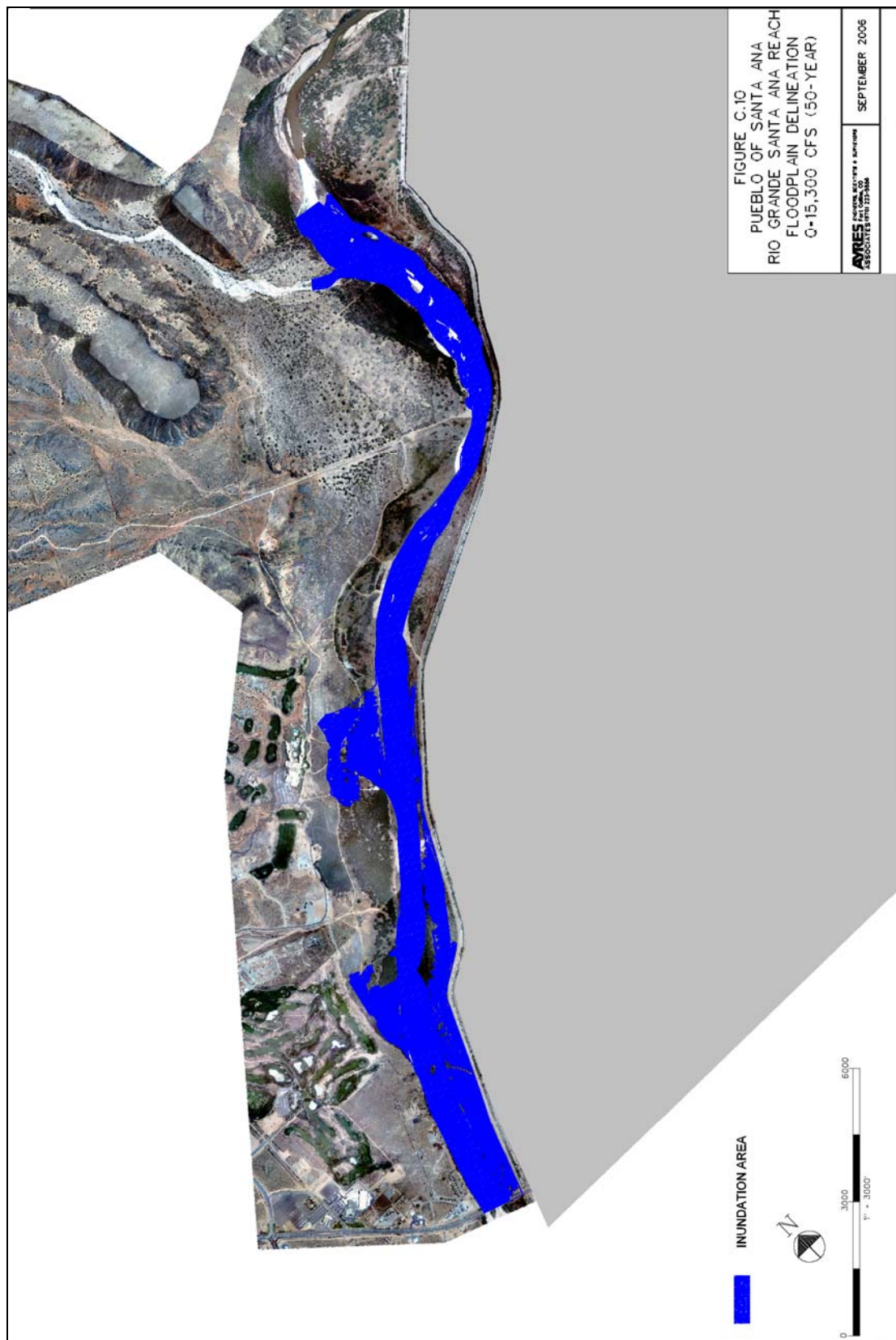
Figure C.10. Floodplain delineation for 15,300 cfs (50-year).
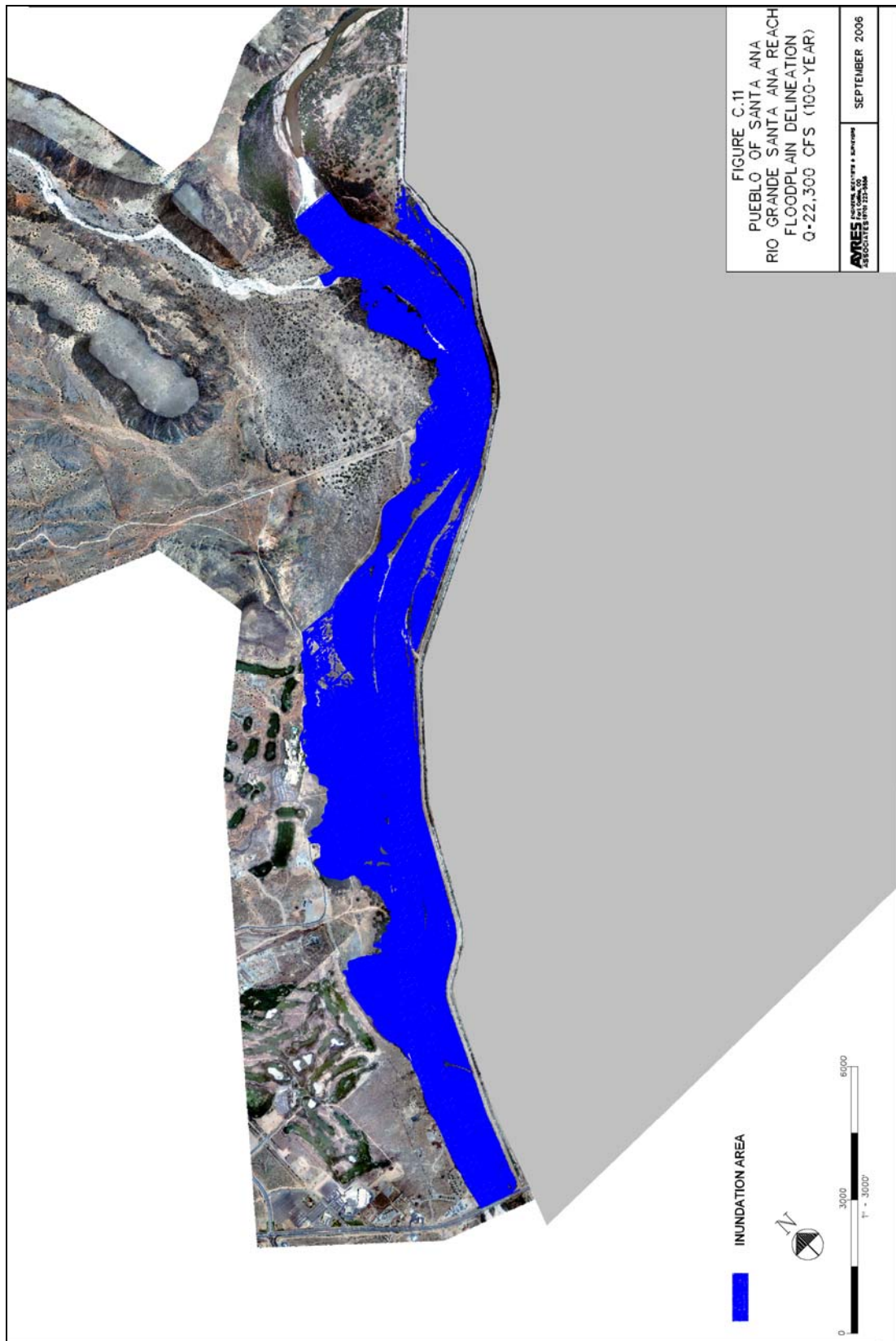
Figure C.11. Floodplain delineation for 22,300 cfs (100-year).

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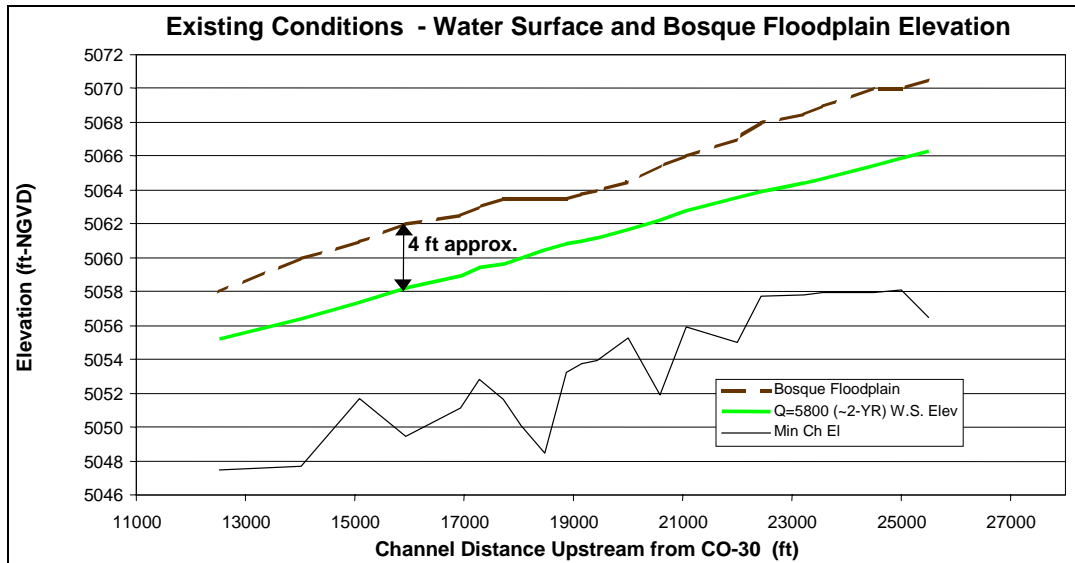
Figure C.12. Water surface and overbank profiles for the effective discharge of 5,800 cfs.

Overbank Lowering

Overbank lowering was investigated to restore shallow flow habitat. Overbank lowering was not considered in the bosque floodplain, but on the more recently active sandbars between vegetation lines of the historical bosque. The objective was to create additional riverine habitat by providing more frequent off-channel inundation and side channel flows. To accomplish this, the overbank areas are to be lowered to initiate overbank flooding at the 2-year discharge of 5,400 cfs. The overbank modification is to be accomplished by uniformly lowering the topography of the existing overbank including side channels by designated amounts. The overbanks will be uniformly excavated to preserve the relative topography and diversity within the overbank areas. Water surface profiles and overbank topography were used to designate the amount of overbank lowering. A depth of flow of 0.5 ft was selected to provide a nominal depth of flow in the overbank areas at the 2-year discharge. Six sandbars were identified for overbank lowering within the project reach as shown on **Figure C.13**.

Channel Widening

Channel widening was investigated as a means to provide a wider and shallower flow area similar to that observed in the past. The concept was to excavate along the channel banks and mechanically widen the channel to a stable width. It was assumed that the channel may widen naturally as a result of grade control, but could also be accomplished through excavation. A wider channel would result in lower velocities and shallower flow depths in the main channel. The trade off with channel widening is that incremental increases in channel width would result in losses in overbank area. At the extreme all overbank areas could be eliminated to provide the widest shallowest channel section possible within vegetation lines. However, it is unlikely that the channel would remain in this state and could return to a width similar to the existing condition.

D/S
Bed Sill

GRF #3

GRF #2

Bar #2

Bar #4

Bar #5

Bar #3

Bar #6

Bar #1

Location of
GRF #1

COCHITI RANGELINE

WIDENED CHANNEL BANKLINE

LOWERED OVERBANK BAR

RIPRAP STRUCTURE

0   1000   2000

1" = 1000'

FIGURE C.13
PUEBLO OF SANTA ANA
RIO GRANDE SANTA ANA REACH
CHANNEL RESTORATION
HYDRAULIC
DESIGN ALTERNATIVES

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Channel width is highly dependent on river hydrology and is a difficult parameter to predict with imposed conditions. Channel geometry relationships commonly used to predict channel width have been developed from data on natural stable rivers. These relationships indicate that a channel in regime would widen under flatter slope conditions. However, applying sediment continuity yields the opposite result. This approach has the advantage that sediment supply is accounted for and results in a channel narrowing as the slope decreases. This is the observed trend for the Rio Grande in the Santa Ana reach.

Hydraulic models representing a mechanically widened channel were developed for the analysis of restoration alternatives. The channel was widened by approximately 25% using a balanced cut and fill between the channel bank and bed. Material cut from the channel banks was assumed to be deposited in the channel to provide the widened channel section. The resulting widened sections were incorporated in the hydraulic models. The limits of the wider channel bankline are shown in Figure C.13.

C.2.6 Model Simulations - Proposed Conditions

Channel cross sections representing the proposed conditions were incorporated into HEC-RAS hydraulic models. The model cross sections were modified to represent the without-project condition, overbank lowering and widened channel. Interpolated cross sections were generated to provide additional resolution through the GRFs. Three separate models were developed for the analysis of restoration alternatives as follows:

(1) Without-project
(2) Overbank lowering
(3) Channel widening

The without-project model provided a basis for determining the additional benefit of adding overbank lowering or channel widening components. A view of the restoration plan hydraulic alternatives is presented in Figure C.13.

Once the GRF models were evaluated, overbank lowering and channel widening were incorporated to analyze these proposed conditions. The long-term performance of these channel modifications is dependent on the stabilized channel with the GRFs. For simplicity the hydraulic effects of overbank lowering and channel widening were analyzed independently although these modifications could be implemented simultaneously. Water levels corresponding to the existing conditions with GRFs at the 2-year discharge were plotted on the channel cross section to determine appropriate amounts of overbank lowering.

C.2.7 Hydraulic Model Results

Results from the 1-dimensional hydraulic modeling efforts were used for comparative analysis of the restoration alternatives. Values were computed for the main channel and overbank areas. The main channel was identified within the banks of the dominant conveyance section. High flow side channels and point bars were designated as overbank. The hydraulic variables were averaged based on length from results at cross sections upstream of the GRF locations.

The hydraulic results indicate that the restoration alternatives will provide more favorable riverine habitat as compared to the existing condtion. With respect to habitat on the Middle Rio Grande, slower velocites and shallower depths are more desirable conditions.

The historic Rio Grande channel was much wider and provided shallower depths and slower velocites than the incised channel of today. The Rio Grande Silvery Minnow Recovery Plan (USFWS 1999) indicates that the silvery minnow prefer areas with little or no velocity and shallow depths. Therefore restoration alternatives that increase the amount of off-channel flow are desirable. Regarding redeposition of sediment in the lowered overbank areas, there is potential for minor redeposition of fines, but redeposition of significant amounts of sand and gravel bed load is not anticipated. Hydraulic variables and the percent difference as compared to the 50-year future condition at the 2-year discharge (5,400 cfs) area listed in **Table C.2**.

Table C.2. Channel Hydraulic Variables and Percent Difference Compared to the "No Action" Future Condition at the 2-Year Discharge.								
	Channel Topwidth		Channel Velocity		Channel Depth		Channel Width/Depth	
	(ft)	% change	(fps)	% change	(ft)	% change		% change
Future Condition	241		4.0		5.3		45.6	
Overbank Lowering	243	+0.8	4.0	0.0	5.1	-3.8	47.8	+4.8
Channel Widening	291	+20.8	3.9	-2.5	4.5	-15.1	64.9	+43.3

The channel topwidth shows a nominal increase with overbank lowering as compared to the future condition. Channel widening may yield an additional 21% increase in width, but as mentioned previously there is no garauntee that the channel width would remain as excavated. The restoration alternatives did not result in significant decreases in channel velocity. Channel depths show decreases by approximately 4 to 15% as a result of the restoration alternatives. The parameter of width/depth will increase by approximately 5% from overbank lowering and increase by approximately 43% with channel widening as compared to the future condition.

Hydraulic changes in off-channel areas (overbanks and side channels) provided by the restoration alternatives will provide increased habitat in these areas. Hydraulic variables for the overbank areas are listed in **Table C.3**.

Table C.3. Overbank Hydraulic Variables at the 2-Year Discharge.								
	Percent Discharge in Overbank		Overbank Cross Section Area		Overbank Topwidth		Overbank Depth	
	%	% change	ft^2	% change	ft	% change	ft	% change
Future Condition	5.5		174		143		1.2	
Overbank Lowering	8.9	+61.8	314	+80.5	281	+96.5	1.1	-8.3
Channel Widening	6.4	+16.4	177	+1.7	142	-0.7	1.2	0.0

Model results indicate that the largest benefit in the overbank areas would be realized with overbank lowering. This can be observed by the increase in overbank discharge, cross section area and topwidth. An additional parameter for gaging the benefit from restoration alternatives is inundation area. This is the total wetted area for a particular discharge. The inundation area was computed as the cumulative product of topwidth and length between cross sections. Inundation areas for the lower Santa Ana Reach are presented in **Table C.4**.

Channel widening would provide more wetted area in the channel for flows less than the 2-year discharge (5,400 cfs), but overbank lowering will yield more inundation above this discharge. Additionally the increased inundation area created by channel widening is within the main stem of the river. This may not provide as much habitat benefit as overbank inundation.

	Existing Condition	Overbank Lowering		Channel Widening	
Q	(ac)	(ac)	% change	(ac)	% change
1,000	69	73	+5.8	96	+39.1
2,000	86	93	+8.1	112	+30.2
3,000	101	113	+11.9	125	+23.8
4,000	113	135	+19.5	136	+20.4
5,400	131	165	+26.0	156	+19.1
7,000	163	185	+13.5	180	+10.4

Table C.4. Inundation Areas and Percent Change Compared to the "No Action" Future Condition for Various Discharges.

C.2.8 Preliminary Quantities

Estimates of quantities required to implement the restoration alternatives were computed for cost estimating purposes. Overbank lowering and channel widening require quantities for excavation and clearing and grubbing. Relocation (haul) quantities for these materials were not computed. Quantities based on dimensions selected for the 2-dimensional hydraulic modeling analysis are listed in **Table C.5**.

Restoration Feature	Clearing and Grubbing (ac)	Overbank Excavation (yd^3)
Overbank Lowering	15.6	170,588
Channel Widening	12.1	107,180

Table C.5. Interim Restoration Feature Construction Quantities.

C.2.9 Discussion

The 1-dimensional hydraulic modeling effort was used to examine the benefits that can be expected from the restoration alternatives. Results from the analysis indicate that both overbank lowering and channel widening could stabilize the Santa Ana reach and provide an improved riverine habitat as compared to the expected future "no action" condition. The hydraulic results indicate that channel widening and overbank lowering could enhance the riverine habitat by increasing the availability of areas of low depth and velocity. However

channel widening was eliminated as a restoration alternative due to the indeterminacy in predicting whether the channel will widen or would revert to narrowing. Therefore the preferred alternative for further analysis and design is overbank lowering.

C.3   Two-Dimensional Hydraulic Modeling

Two-dimensional hydraulic modeling was performed to verify results from the preliminary analysis and to refine the design of the habitat restoration features. The hydraulic design included the two recently constructed gradient restoration facilities (GRFs) and overbank lowering. Because the downstream bed sill will have no initial effect on channel hydraulics, it was not included in the hydraulic analysis. The extents of the 2-dimesional model included the Santa Ana reach as shown in **Figure C.14**. The model provided additional data to assess the impacts that may be created by the design. This section describes the methodology, approach, and findings of the analysis.

C.3.1 Methodology - Two-Dimensional Hydraulic Modeling

Hydraulics within the Santa Ana include flow within the main channel and overbanks, flow splits around mid-channel bars and flow in overbank side channels. The hydraulic behavior of a system of this complexity can be evaluated accurately with a 2-dimensional hydraulic model. In this context, 2-dimensional means that hydraulic variables are considered in two dimensions of the horizontal plane (x and y) and velocity is averaged over the depth of flow.
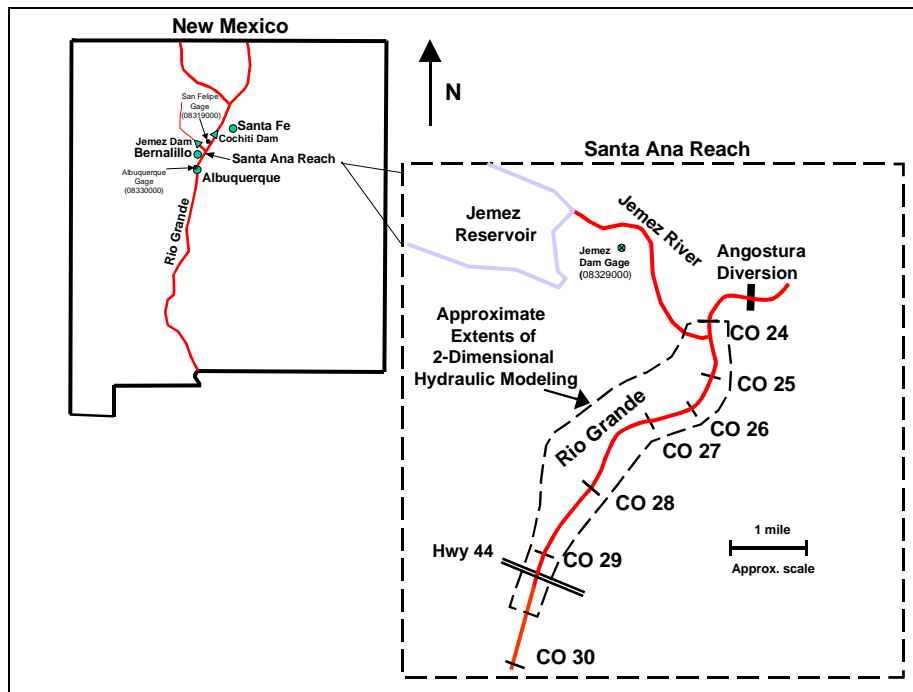

Figure C.14. Location map of Santa Ana Reach and extents of 2-dimensional model study.

Simulations for this model study were performed using RMA2, a 2-dimensional, depth averaged, finite element hydrodynamic numerical model. RMA2 is maintained by the U.S. Army Corps of Engineers Waterways Experiment Station (WES 1998). The model solves the equations of 2-dimensional flow for shallow surface water. The governing equations include conservation of mass and momentum in two dimensions. The program solves for flow depth and velocity at discrete points, called "nodes" throughout the system. Data requirements for RMA2 include a geometric representation of the system with appropriate boundary conditions.

Geometric input for RMA2 includes a 3-dimensional representation of the system with a finite element mesh (FEM). This mesh is a network of nodes and elements, that characterize the topography, bathymetry and hydraulic resistance of the system. Mesh elements are 3- or 4-sided polygons representing planar surfaces and nodes delimit the elements and define their elevation and slope in space. The network of elements and nodes act as a digital elevation model (DEM) of the system.

Each element in a FEM is assigned hydraulic resistance parameters. These parameters include friction factors and turbulent exchange coefficients that are used to compute energy losses of flowing water. Friction factors are usually expressed in terms of Manning's n values, which are influenced by vegetation, sediment size, bed forms and obstructions. Another method of modeling flow resistance is with equivalent roughness height, where the friction factor becomes depth dependent. When using Manning's roughness coefficient, a constant friction factor is applied for all flow depths. For modeling friction losses at the gradient restoration facilities (GRFs), the RMA2 code was modified by Ayres Associates to include the option for equivalent roughness height. This option utilizes the Kuelegan relationship (1938) which allows for the computation of a Manning roughness coefficient based upon depth of flow and equivalent roughness, K_s. Based upon technical literature relevant to the design, K_s was computed as 2.2 times the median riprap size (D_{50}).

Model boundary conditions are defined along the exterior nodes of the finite element mesh. At locations where the model boundary is closed flow is constrained to remain within the model boundary. At locations where flow can leave or enter the model by crossing the open boundary, a condition is specified which constrains the model by either a discharge or by water surface elevation. In this model study, the external open boundary conditions were discharge at the upstream limit of the model and water surface elevation at the downstream boundary.

C.3.2 Model Development

The layout of the finite element mesh was developed using planimetric data from orthophotographic aerial images of the project area exposed in 1997. At different stages of this project, additional survey data was collected to support the analysis. The original aerial mapping of the project reach was completed in 1997, and later updated with 2001 overbank and channel cross sections. In 2005, several post-construction channel cross sections and overbank areas in the vicinity of the GRFs were resurveyed.

Figures C.15 and C.16 are illustrations of the networks (finite element mesh) used for the simulations. All of the lower reach models extended downstream to approximately 2,000 feet downstream of the Highway 550 bridge in Bernalillo. The lower reach models were to represent the portion of the river to be stabilized within the scope of the 1135 USACE/Pueblo of Santa Ana project. The Santa Ana Reach model included the lower and upper reaches in

the network. Channel widening was not included in the 2-dimensional model because this alternative was dropped as described previously.

Following development of the finite element meshes (FEM's), elevations were assigned to each of the nodes. Elevation data was obtained from a digital terrain model (DTM) of the reach. The original DTM included elevations for above water features so it was modified to include bathymetric data.

Elevations from the modified DTM were superimposed onto the FEM and elevations were assigned to the mesh nodes. Some manual manipulation of nodal elevations was required after the automatic assignment step to represent certain features accurately. Through this process a network was developed to represent the topographic and bathymetric features of the Santa Ana Reach. A comparison of a surveyed cross section and ground elevations represented in the 2-dimensional model FEM is illustrated in **Figure C.17**.

C.3.3 Model Calibration

Each element in the FEM network was assigned a material type to represent hydraulic roughness within the reach. Material types were defined for several categories of ground cover types including channel and varying vegetation densities in the overbanks. The Manning's n values for each element type was estimated using information from the 1-dimensional models developed previously. Additionally equivalent roughness values were used to model depth dependent roughness for the GRFs. The roughness height used for the GRFs was based on a riprap size of D_{50} = 12 inches. Research indicates that the roughness height of uniformly graded riprap is approximately 2.2 D_{50}. The Manning's n and equivalent roughness values (Ks) for various material types are listed in **Table C.6**.

Table C.6. Two-Dimensional Model Roughness Values.	
Material Type	Roughness Value
Channel	0.026
Channel Bank	0.026
Overbank Sand	0.03
Overbank Medium Density Vegetation	0.07
Overbank Dense Vegetation	0.1
Overbank Light Density Vegetation	0.04
Bosque Overbank	0.09
GRF Riprap	Ks = 2.2 ft
GRF Riprap Bank	Ks = 2.2 ft

Channel Manning's n values used for the 1-dimensional model analyses varied from 0.024 in the upper reach to 0.032 as affected by channel irregularities, bendways and mid-channel bars. The additional losses associated with these features are implicitly represented in the 2-dimensional geometry and therefore, it is reasonable that 2-dimensional channel n values are lower than those used in the 1-dimensional model.

BOSQUE OVERBANK
MESH

LOWER
REACH
MESH

FIGURE C.27
PUEBLO OF SANTA ANA
RIO GRANDE SANTA ANA REACH

FINITE ELEMENT MESH
LOWER REACH MODELS

AYRES
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Fort Collins, CO
(970) 223-5556

SEPTEMBER 2006

0   1500   3000
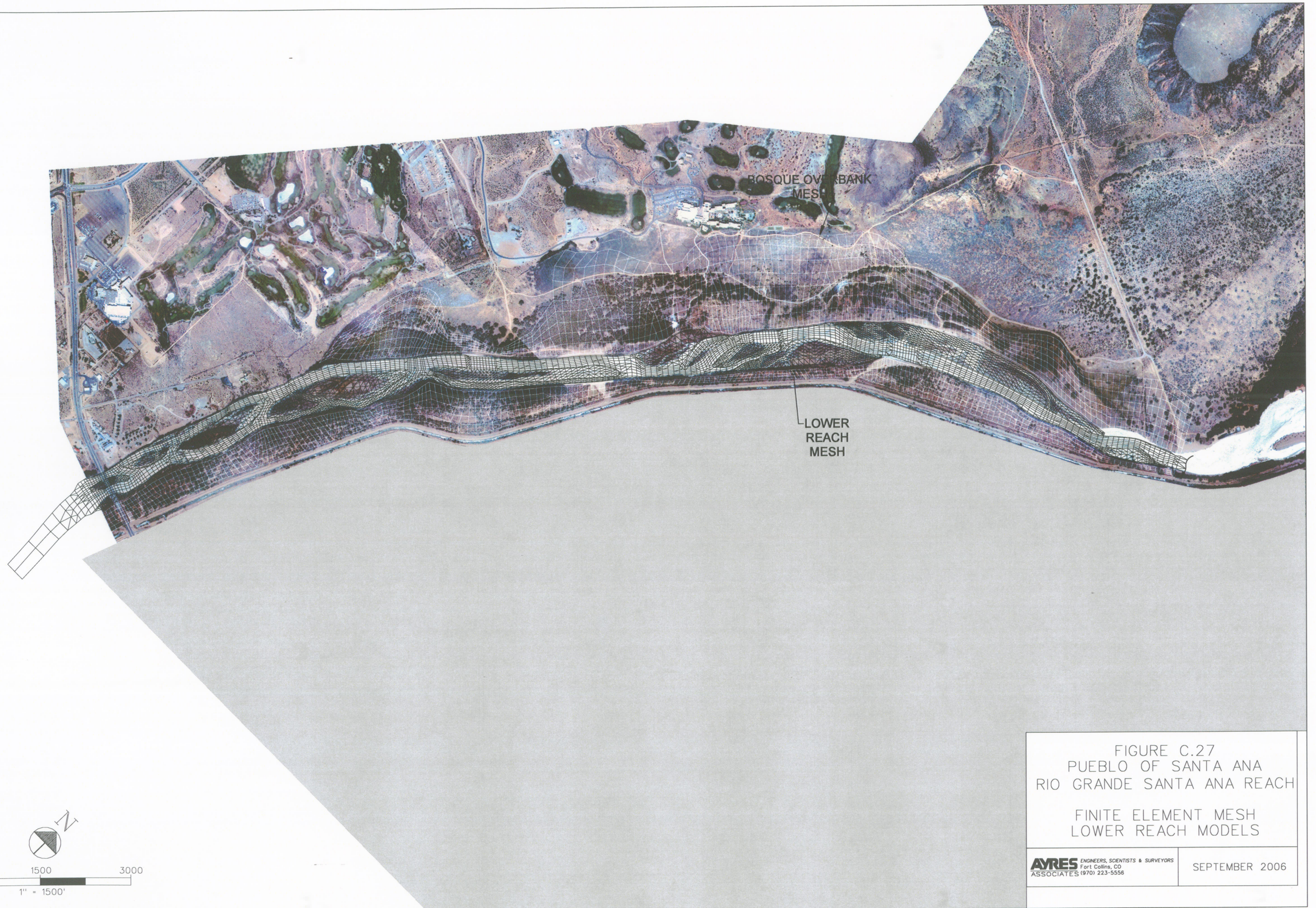
1" = 1500'

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FIGURE C.28
PUEBLO OF SANTA ANA
RIO GRANDE SANTA ANA REACH
FINITE ELEMENT MESH
UPPER REACH

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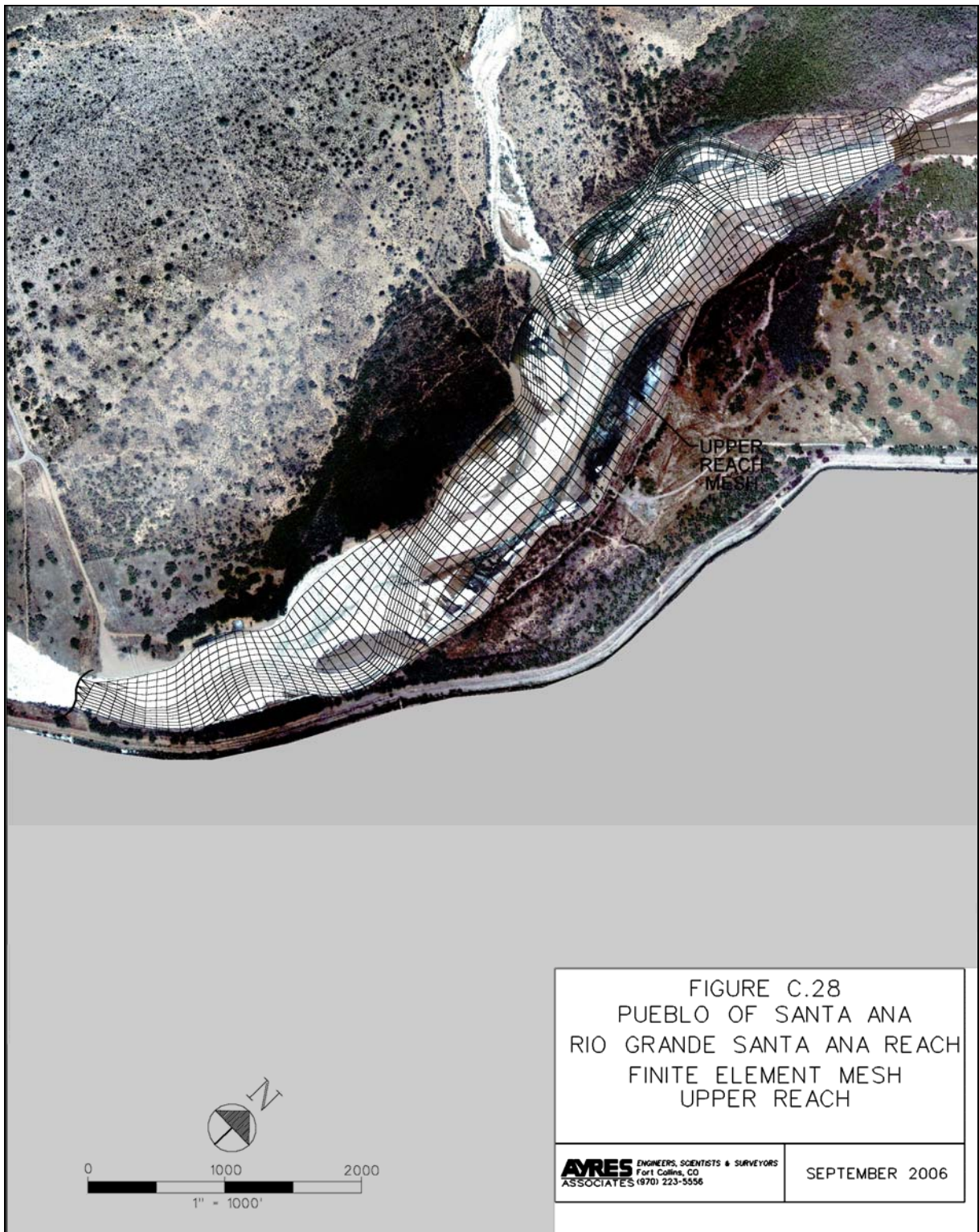
Figure C.16. Upper reach finite element mesh.
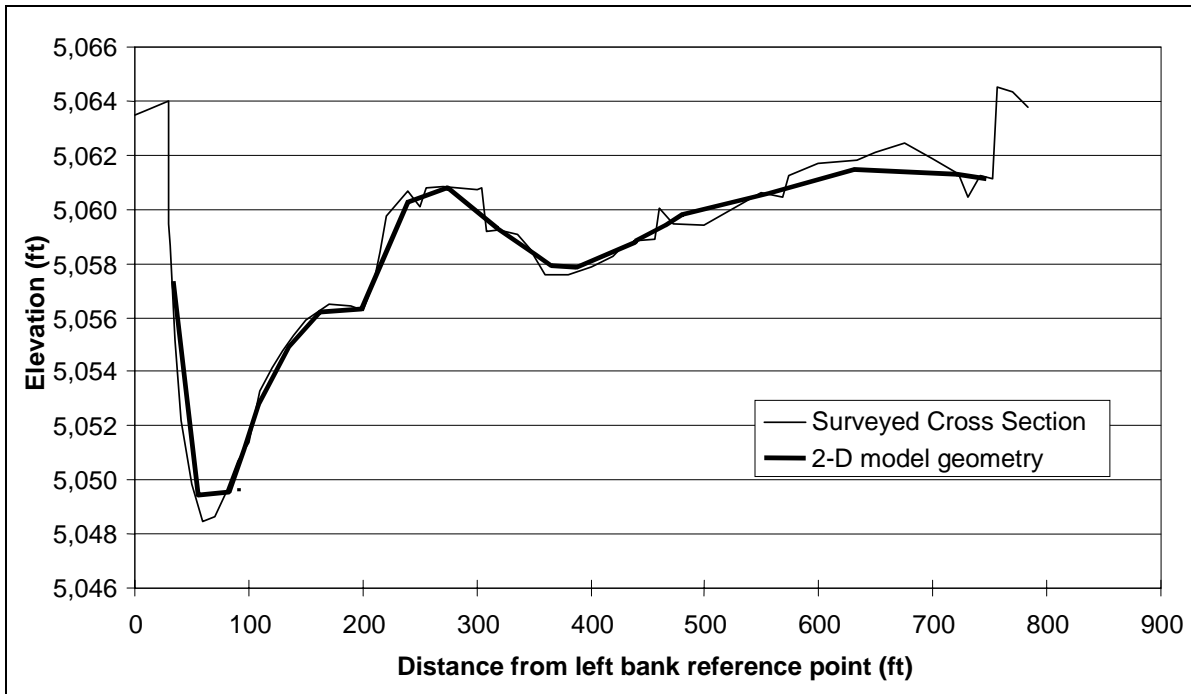
Figure C.17. Representative surveyed cross section and 2-dimensional model representation.

A single Manning's n value was used for the channel in the 2-dimensional model study. This n value corresponds to the grain roughness of the bed material. The Limerinos (1970) equation for grain roughness was used to estimate the value in the following equation:

$$n = \frac{0.0926Y^{\frac{1}{6}}}{1.16 + 2.0\log\left[\dfrac{Y}{D_{84}}\right]} \tag{C.2}$$

where:

n	=	Manning's n coefficient
Y	=	Flow depth, ft
D_{84}	=	Bed material size of which 84% is finer by weight (ft)

Sieve analyses of bed material samples obtained in August 1999 provided gradations of bed material size within the Santa Ana Reach. Samples were collected in the main channel and overbank areas at 14 cross sections throughout the project reach. Several samples were collected at each cross section and the gradations within the channel were averaged for each section. Overbank samples were not averaged for the evaluation of channel grain roughness. The channel gradation values were averaged over the length of the reach and are listed in **Table C.7**.

Table C.7. Santa Ana Reach Average Channel Bed Material Gradation.	
Percent Finer By Weight	Grain Size (mm)
16	0.5
35	3.5
50	7.4
65	13.1
84	24.5
90	30.5
95	35.3

For the range of flow depths expected in the Santa Ana Reach the Limerinos equation results in a Manning's n value of 0.026.

The 2-dimensional model calibration was accomplished through comparison of water surface profiles from the calibrated 1-dimensional model. Since a reasonable calibration was achieved with the 1-dimensional model, it provided a basis of comparison. The 2-dimensional model calibration required adjustments to the model geometry more than the channel roughness value. Because there was limited channel survey in the project reach, the initial model bathymetry at split flow locations was not representative of field conditions. The discrepancy was indicated in the variance in water surface elevation at split flow locations. This is significant in a 2-dimensional model because amount of flow into these areas is dependent on the entrance condition. If the split flow entrance is represented incorrectly, then the amount of flow entering the side channel will be incorrectly computed and the water surface profile will be affected accordingly. Therefore the bathymetry of these transitions were modified to match the calibration water surface profiles. Comparison profiles from the 1-dimensional model (HEC-RAS) and the calibrated 2-dimensional model are presented in **Figure C.18**.
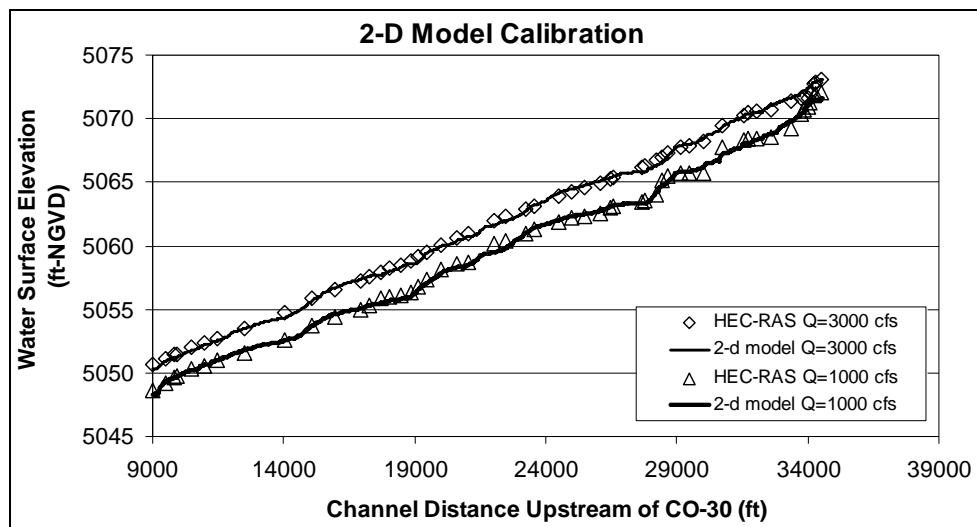

Figure C.18. Comparison profiles for the 2-dimensional model calibration.

C.3.4 Two-Dimensional Model Simulations

The calibrated 2-dimensional model provided a tool for design and for comparison for restoration alternatives. Volumes of overbank lowering were adjusted using results from the 2-dimensional model. Several model geometries were developed, but only the lower reach models were used for analysis of restoration alternatives.

Refinement of Preferred Design Alternatives

The preferred hydraulic restoration feature that was selected from the preliminary alternative development included overbank lowering. Channel widening was excluded as an alternative based on results from preliminary investigation.

The two-dimensional model geometry used for the 2001 hydraulic analysis of the final GRF design was updated to incorporate recent channel cross section surveys completed by Ayres Associates in 2005. These cross sections were merged into the existing overbank topography to create a seamless topographic surface surrounding the project area. After this was complete, the original model geometry was updated to reflect changes in the topography from the downstream end of the U.S. Bureau of Reclamation (USBR) GRF to the Bernalillo Bridge (Hwy 550). Material types, representing different roughness values, were updated to reflect changes due to GRF construction and any channel and vegetation changes that have occurred since the previous modeling effort.

Using the updated model geometry, model simulations were performed for seven river flows: 500, 1,000, 2,000, 3,000, 4,000, 5,400 (2-year event), and 7,000 cfs. This updated model condition serves as the baseline for preferred habitat improvements.

Modifications to overbank lowering quantities were determined from initial analysis of the 2-dimensional model results. The 2-dimensional model provided computational tools for determining the amount of overbank lowering that would be required to initiate flooding at the 2-year discharge. Within the project reach six sandbars were identified for overbank lowering as shown in **Figure C.13**. Using results from the 2-dimensional model, discrete lowering depths were selected for each of the sandbars.

The initial lowering scenario is referred to as Lowering Scenario A. In addition to this scenario, two other model geometries were developed to evaluate different levels of overbank lowering. To help identify the optimal lowering amounts, scenarios with 0.5 feet less (scenario B) and 0.5 feet more (scenario C) lowering were created. **Table C.8** provides a summary of the lowered bar amounts and computed excavation quantities associated with each scenario. Modeling simulations were performed for all three scenarios at each of the seven discharges to provide preferred habitat comparisons.

Table C.8. Summary of Overbank Lowering Depths and Associated Volumes for Three Lowering Scenarios.

		Overbank Lowering Scenario						
		A		B		C		
Bars	Area (ac)	Amount Lowered (ft)	Volume (yd³)	Amount Lowered (ft)	Volume (yd³)	Amount Lowered (ft)	Volume (yd³)
1	13.81	2.0	44,507	1.5	33,380	2.5	55,634
2	10.60	1.5	25,629	1.0	17,086	2.0	34,171
3	21.75	1.0 – 1.5	47,765	0.5 – 1.0	30,234	1.5 – 2.0	65,296
4	7.27	2.0	23,443	1.5	17,582	2.5	29,304
5	1.73	1.5	4,183	1.0	2,789	2.0	5,577
6	7.07	2.2	25,061	1.7	19,366	2.7	30,757
TOTAL	62.23	-	170,588	-	120,436	-	220,740

Preferred habitat was identified as those areas that are utilized most frequently by fish. Data from fish counts provided information on the frequency of usage for certain hydraulic conditions. Areas of maximum usage were assumed to be preferred habitat. Data presented in the "Rio Grande Silvery Minnow Recovery Plan" (USFWS 1999) were used to identify areas of maximum usage. Distributions of habitat availability and use by silvery minnow from the recovery plan are shown in **Figures C.19 and C.20**. It is assumed that the data used to produce these figures was collected at a range of discharges. The recovery plan indicates that silvery minnow were most frequently found in areas of little or no velocity and shallow depth. The figures indicate that the most species were observed in depth ranges of 10 - 60 cm (0.3 - 2.0 feet) and areas where the velocity was less than 20 cm/s (<0.7 ft/s). The recovery plan also indicated that the minnow tend to shift to deeper water in the winter, but these areas were generally typified by lower velocities during this season. Therefore areas with hydraulic parameters similar to the locations where the most species were found are considered to be preferred habitat. These parameters are also supported by data in the current draft revised recovery plan (USFWS 2007).

Results from the 2-dimensional model allowed for computations of multi-parameter habitat availability. Because the model provides hydraulic parameters in the horizontal plane, surface areas that include particular combinations of depth and velocity can be readily quantified. A software program, developed by Ayres Associates, was used to delineate the preferred habitat areas, which are defined as those having flow depths less than 2.0 ft and velocities less than 1.0 ft/s   Acreages of preferred habitat availability were summed for each model simulation and are shown in **Figure C.21**. These acreages were calculated for a project area extending from the downstream end of the USBR GRF to the upstream end of the Bed Sill structure. The model results indicate that all of the lowered bar alternatives increase habitat amounts for discharges up to 5,400 cfs and decrease habitat for the 7,000 cfs discharge. As stated in the original report, flows in excess of 7,000 cfs have been exceeded approximately 0.5% of the time during the post-dam era. Therefore the decrease in preferred habitat during flood flows is insignificant when compared to the increased benefits at lower discharges. Overall, Scenario C, with the most lowering appears to provide the greatest habitat improvement over the normal flow range. However, the excavation volumes are roughly 30% greater than Scenario A. Therefore, the additional cost for the incremental habitat increase between Scenario C and A is not likely substantiated.
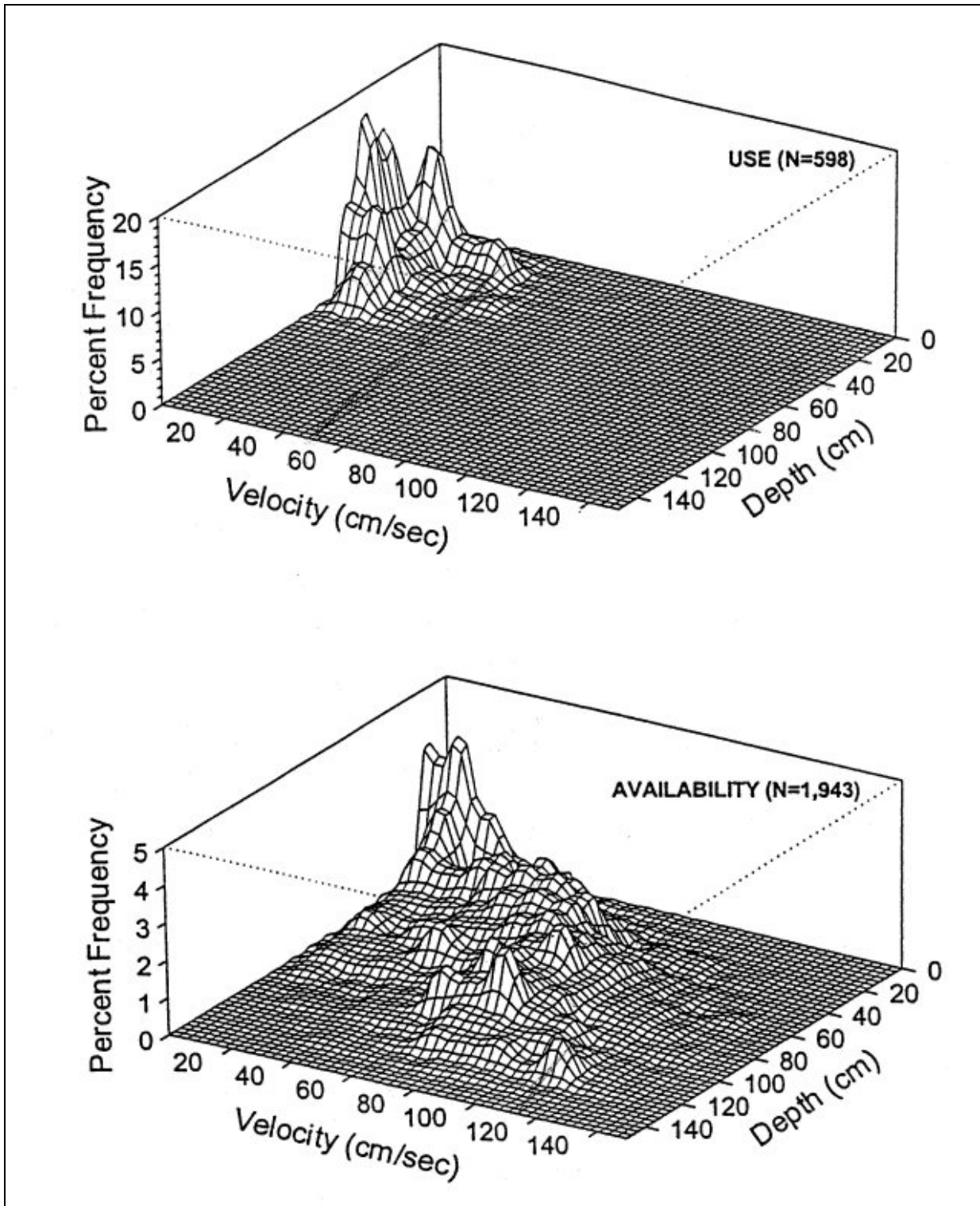
Figure C.19. Comparison of depth-velocity availability and use by Rio Grande silvery
minnow at the Rio Rancho sampling locality in the Rio Grande
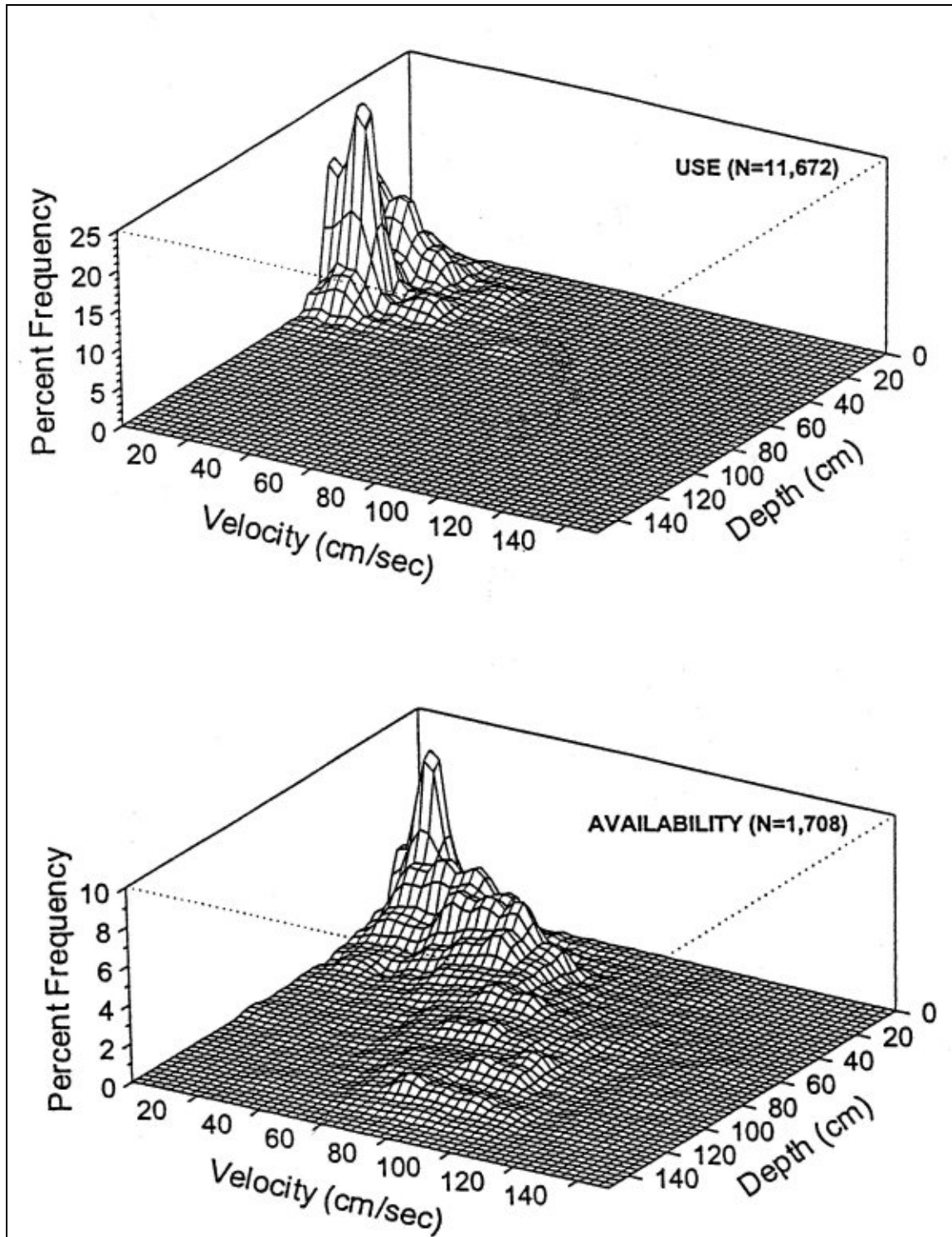(from USFWS 1999).

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Figure C.20. Comparison of depth-velocity availability and use by Rio Grande silvery minnow at the Socorro sampling locality in the Rio Grande (from USFWS 1999).
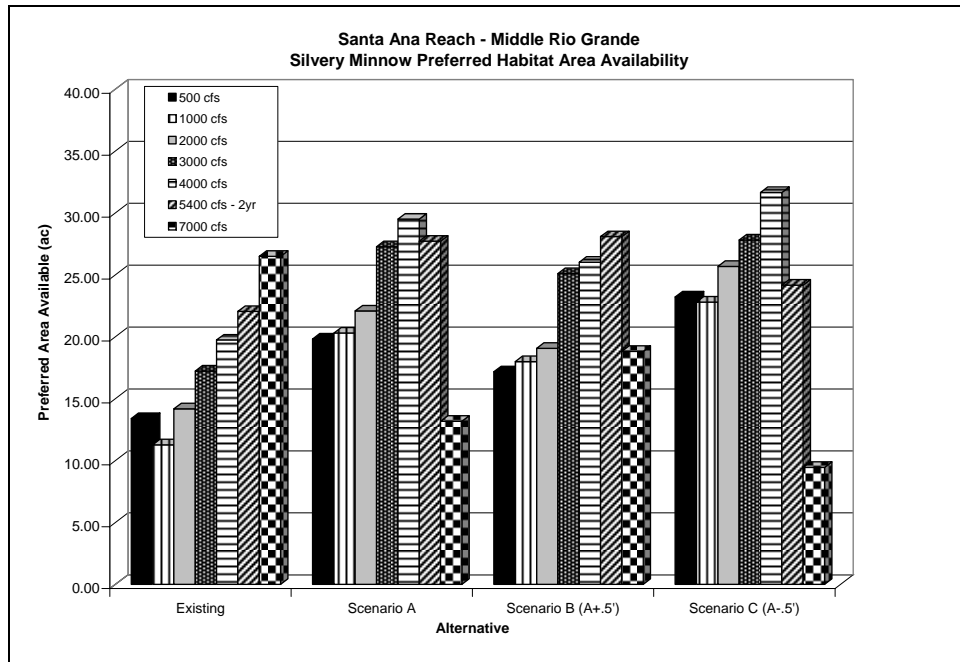
Figure C.21. Amount of silvery minnow preferred habitat for the existing and three overbank lowering scenarios.

Total wetted area was also calculated using the results from the 2-dimensional model. The total wetted area in the project area is illustrated in **Figure C.22**. There is not a large increase in wetted area for and of the lowered bar alternatives. **Tables C.9 and C.10** provide a summary of the values used to generate the figures.
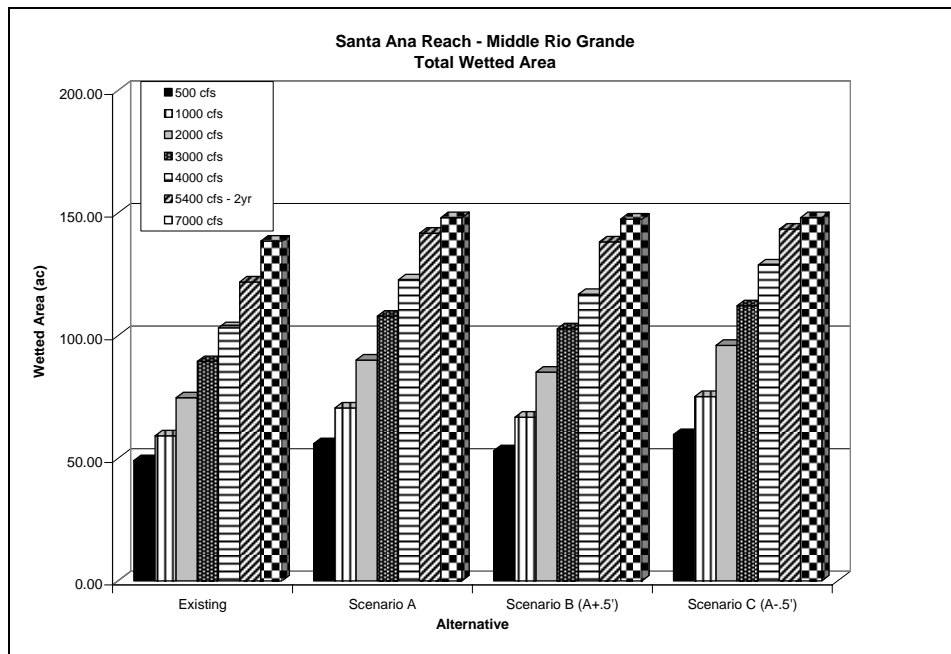

Figure C.22. Total wetted area for existing and three overbank lowering scenarios.

Table C.9. Silvery Minnow Preferred Habitat Area.				
Model Condition				
Flow (cfs)	Existing (ac)	Scenario A (ac)	Scenario B (A + .5 ft) (ac)	Scenario C (A - .5 ft) (ac)
500	13.39	19.82	17.17	23.22
1,000	11.27	20.30	18.00	22.81
2,000	14.19	22.09	19.06	25.69
3,000	17.23	27.28	25.10	27.82
4,000	19.74	29.51	26.02	31.66
5,400	22.05	27.72	28.09	24.17
7,000	26.50	13.17	18.82	9.46

Table C.10. Total Wetted Area.				
Model Condition				
Flow (cfs)	Existing (ac)	Scenario A (ac)	Scenario B (A + .5 ft) (ac)	Scenario C (A - .5 ft) (ac)
500	49.08	55.96	53.11	59.69
1,000	59.19	70.54	66.74	75.15
2,000	74.68	90.08	85.14	96.08
3,000	89.48	107.94	102.76	112.21
4,000	103.24	122.77	116.88	128.84
5,400	121.89	141.80	138.22	143.46
7,000	138.59	148.14	147.53	148.15

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